MASTER

XXVII

The Relation between Weather and Meadow Hay Yields in England 1939-1956

1. Summary

A very close relationship has been established between yields of meadow hay and a meteorological parameter, namely, estimated actual transpiration during the period of growth. County data for yield and transpiration were combined, using grass acreages as weighting factors, into regional and national values. After an adjustment for a steady improvement in yield during post-war years had been made, the correlation between the actual and calculated yield in England for the years 1939-56, was 0.95. The mean error between the actual yields and the calculated yields was 2.1 per cent., the formula being:-

Yield (cwt/acre) = 7.05 + 1.56T + 0.27N where T = estimated actual transpiration (in)

N = number of years after 1946.

2. Data used

(a) Meadow Hay Yields.

The hay yields for each county in England given in the several volumes of Agricultural Statistics 1939-1956 (H.M.S.O.), were used as the basic data. These data were grouped together into twelve regions of two to five counties using the appropriate areas of grass as weighting factors. These regions were then combined into four main areas, namely North, Midland, East and South, in the same manner. Finally these four areas were combined to give the mean yield for the whole country.

(b) Transpiration

These were based on the values for average Potential Transpiration given in Table 10 of the Technical Bulletin No.4 of the Ministry of Agriculture (The Calculation of Irrigation Need, H.M.S.O.). To obtain the individual values for each of the April to July months of the eighteen years the estimation method (devised by the author) was used. This is described on page 15 of the above bulletin; the deviation from average of potential transpiration is assumed to be proportional to the deviation from the average sunshine in the county or sub-county concerned. Average values (available - the Meteorological Office) were used for March.

Rainfall amounts were taken from official records for one station in each of the areas for which estimated potential transpiration figures were available. To estimate the actual transpiration from these two sets of data, certain assumptions had to be made:-

(i) the soil was at field capacity at the beginning of the growing season

(ii) a constant period between the start of growth and time of harvest could be used throughout, this period differed from Region to Region, the most appropriate mean period being chosen, (An exception was made in 1947 when much of the grass was covered by snow or subsequent flooding during March).

(iii) A soil moisture deficit of 2 inches only was allowed; although it is known that grass can extract more water than this from soil, it was considered that such extraction would not count towards the estimation of actual transpiration (T) which would be effective in assessing growth.

The process of estimating T is shown in the following examples:-

Example 1

County West Norfolk. Station Sprowston Year 1940.

	March	April	May	June 1-15
Potential Transpiration	1.15	1.75	3.30	2.10
Rainfall	2.86	1.40	0.75	0.2
Soil Deficit	Nil	0.35	2.0	2.0 (to nearest 0.05 in.)
Actual Transpiration	1.15 +	1.75 +	2.4 +	0.2 = 5.5 inches

This is a straightforward case. The rainfall exceeded transpiration in March; the soil therefore remained at field capacity and the actual transpiration was equal to the potential. In April the rainfall was 0.35 in. less than the potential, but this deficiency was made up by an increase in the soil moisture deficit of the same amount, the actual transpiration again equalled the potential. In May the rainfall was very deficient. The actual transpiration was made up from the rainfall (0.75 in.) plus the remainder of the permitted soil moisture deficit (2.0 minus 0.35 equals 1.65 in.), thus giving a total of 2.4 in. In June, no further 'effective' water is assumed available from the soil and the transpiration is restricted to the rainfall of 0.2 in.

Example 2

County Shropshire. Station Shrewsbury. Year 1945

	March	April	May	June
Potential Transpiration	1.10	2.35	2.85	3.40
Rainfall	1.01	1.08	3.78	2.00
Soil Deficit	0.1	1.35	0.4	1.8
Actual Transpiration	1.1 +	2.35 +	2.85 +	3.4 = 9.7 inches

The difference here is that the limiting soil deficit was never reached. In May the rainfall exceeded the transpiration and the soil moisture deficit was reduced by the excess. If the rainfall in May had been even greater, the deficit could have been reduced to zero but no further; the soil cannot be wetted beyond field capacity and the remaining water is lost to the drains. The actual transpiration never exceeds the potential.

3. Grouping of counties

The counties were grouped together into 12 regions as follows:-

Region		Counties	Number of sample stations
I	Northeast	Northumberland and Durham	4
II	Northwest	Cumberland, Westmorland and Lancashire	5
III	Yorkshire	East, North and West Ridings	6
	These three regions comprised the NORTH Area		15
IV	Northeast Midlands	Nottingham, Lincoln and Derbyshire	7
V	Central Midlands	Leicester, Rutland, Northampton and Warwickshire	6
VI	West Midlands	Cheshire, Shropshire, Stafford, Hereford and Worcestershire	6
	These three regions comprised the MIDLAND Area		19
VII	Southeast Midlands	Huntingdon, the Soke of Peterborough, Isle of Ely, Cambridge, Bedford and Hertfordshire	5

Region		Counties	Number of sample stations
VIII	East Anglia	Norfolk, Suffolk and Essex	8
IX	Southeast	Middlesex, Surrey, Kent and Sussex	9
	These three regions comprised the EAST Area		22
X	South Midlands	Gloucester, Oxford, Buckingham and Berkshire	8
XI	South Central	Dorset, Wiltshire, Hampshire and Isle of Wight	8
XII	Southwest	Cornwall, Devon and Somerset	8
	These three regions comprised the SOUTH Area		24

The total number of sample rainfall stations was thus 80.

The assumed periods of growth were April to July 10 for Regions I and II (July 15 in Lancashire), April to June 30 in Region III, March to June 30 in Regions IV, V, VI, X and XI, March to June 15 in Regions VII, VIII, IX, and XII.

5. Summary of Results

Evidence was found of a steady increase in yield after the war, unrelated to the current weather. An adjustment to the yields was therefore made (by the method of double regression) assuming a constant improvement per year after 1946.

The yield (cwt. per acre) formulae obtained for the various regions and areas were:-

T = actual transpiration (in.)
N = number of years after 1946

	Region of AREA	Formula	Mean percentage error
I	Northeast	$8.16 + 1.45T + 0.39N$	4.8
II	Northwest	$15.45 + 0.57T + 0.10N$	3.7
III	Yorkshire	$6.94 + 1.62T + 0.22N$	2.9
	NORTH	$9.17 + 1.30T + 0.22N$	3.1
IV	Northeast Midlands	$4.57 + 1.89T + 0.07N$	2.9
V	Central Midlands	$7.15 + 1.29T + 0.34N$	4.1
VI	West Midlands	$6.81 + 1.53T + 0.35N$	2.9
	MIDLAND	$7.28 + 1.45T + 0.27N$	2.4
VII	Southeast Midlands	$1.72 + 2.26T + 0.37N$	4.4
VIII	East Anglia	$1.40 + 2.51T + 0.28N$	5.1
IX	Southeast	$4.01 + 1.89T + 0.43N$	4.1
	EAST	$2.38 + 2.22T + 0.37N$	3.2
X	South Midlands	$5.80 + 1.68T + 0.23N$	4.9
XI	South Central	$7.68 + 1.50T + 0.32N$	4.3
XII	Southwest	$9.56 + 1.47T + 0.19N$	2.8
	SOUTH	$7.65 + 1.57T + 0.25N$	3.1

These results are illustrated in Figures 1 and 2.

Further details are given in the Appendices.

ENGLAND

Formula Yield = 7.05 + 1.56T + 0.27N cwt/acre

YEAR	YIELD	T	1.56T	0.2TN	CALC. YIELD	ERROR
1939	19.8	7.7	12.01		19.1	-0.7
1940	17.1	6.5	10.14		17.2	+0.1
1941	19.3	7.4	11.54		18.6	-0.7
1942	19.1	7.8	12.17		19.2	+0.1
1943	19.7	8.0	12.48		19.5	-0.2
1944	16.2	6.4	9.98		17.0	+0.8
1945	20.8	8.4	13.10		20.1	-0.7
1946	19.5	8.4	13.10		20.1	+0.6
1947	18.9	7.4	11.54	0.27	18.9	0.0
1948	20.6	8.8	13.73	0.54	21.3	+0.7
1949	19.9	7.5	11.70	0.81	19.6	-0.3
1950	20.8	7.8	12.17	1.08	20.3	-0.5
1951	20.8	8.4	13.10	1.35	21.5	+0.7
1952	21.7	8.3	12.95	1.62	21.6	-0.1
1953	22.8	8.3	12.95	1.89	21.9	-0.9
1954	21.4	8.0	12.48	2.16	21.7	+0.3
1955	23.0	8.8	13.73	2.43	23.2	+0.2
1956	20.7	7.0	10.92	2.70	20.7	0.0
				Mean error		0.42
				Mean percentage error		2.1%
				Correlation between actual and calculated yields		0.95

These results are illustrated in Figure 3.

5. Discussion

The accuracy of the yield figures is not known, but it has to be ignored. For the purposes of combining the yields into regional figures, the process of weighting by factors in terms of thousands of acres will introduce errors, but the same weighting factor is used both for yields and transpiration so that the inter-relationship will not be affected.

Much depends on the assumptions stated in paragraph 2(b). The first assumption regarding field capacity at the end of winter is normally true. The second assumption regarding a fixed period from start of growth to harvest is inevitable as more precise timing would be very difficult to obtain and even if available, would lead to an immense amount of extra work. The third assumption of a limiting soil deficit has some justification. Using similar data it is known that a deficit of two inches prevails at the time of peak grass production in New Zealand, and at the time of peak milk production in England and Wales. The absolute accuracy of the figures of 2 inches rests largely on the relative accuracy of the rainfall and potential transpiration figures.

There is an increasing amount of evidence, based both on field experiments and ecological considerations to show these data are indeed relatively accurate. If they do contain errors, such errors are of the same order and in the same algebraic sense. The potential transpiration figures used, however, were not calculated by the full Penman method. They were obtained by an approximate method which can introduce errors up to 0.25 in. per month, but probably not exceeding 0.5 in. over the period considered.

The taking of only one sample rainfall station per county or sub-county is bound to introduce a further possible error. Although this means that some 4 to 9 samples were considered per region, it is presumptious to regard the result as highly accurate. The estimated error in extreme cases is probably 0.75 in., when it is remembered that most hay is taken from lowland areas. This error clearly becomes smaller as the number of sample stations increase.

For the total meteorological error therefore, it might be suggested that the maximum could be 1.25 in. in the Regions, 1.00 in. in the four main Areas and 0.75 in for the country as a whole. This would imply mean errors of the order of 0.5 in., 0.35 in. and 0.25 in. respectively. Comparison with the actual errors can be facilitated by using the regression factor to convert the error in inches to the error in yield; examination of the mean errors in the Regions shows that 7 out of 12 fall within this suggested limit. Of the remainder, four are very close to the estimate, and only one, the Northwest (Region II) is badly astray, this being affected by the very small regression factor. Of the individual errors in the Regions 31 out of 216 are greater than $\pm$ 1.5 cwt/acre, and nearly half lie within $\pm$ 0.5 cwt/acre. In the larger Areas, only one calculated yield out of 72 is in error by more than 1.5 cwt/acre.

Analysis of the errors in the larger areas shows:-

	Estimated mean error	Actual mean error
NORTH	0.46	0.61
MIDLAND	0.51	0.49
EAST	0.75	0.60
SOUTH	0.55	0.65
ENGLAND	0.39	0.42 cwt/acre

The agreement is encouraging.

The main source of non-meteorological error, the variation of the period of growth, has already been discussed. It is worth noticing however, that the estimated date of the end of this period in the extreme northwest (July 10 in Cumberland and Westmorland) and extreme southwest (June 15) is somewhat earlier than one might expect. This is probably a reflection of another relatively large source of error, namely, conditions during harvest. In these areas in particular, the not uncommon rains of mid-summer would increase the estimates of T, but would militate against a good harvest. The selection of an early date for the end of the growth period thus tends to include some partial effect of the otherwise ignored factor of harvest conditions.

The increased use of fertilizer is another potent factor on yield and this is taken into account by the post-war adjustment in yield. The assumption of a steady increase per year is probably inaccurate, but the resulting error cannot be large. It is perhaps significant that although little change can be seen during the war, 1939 is often a 'rogue' year; prewar husbandry probably explaining this.

Finally, no notice has been taken of autumn and winter rainfall, which causes leaching, or of autumn husbandry which is known to effect spring growth. The accuracy of the results already obtained suggests that, over large areas, these effects must be relatively small.

6. Conclusions

(1) The Meadow Hay yields in England bear a closer relationship to the estimated effective transpiration than to any other meteorological parameter yet tried.

(2) As a result, it can be suggested that when temperature permits, maximum grass growth occurs when the soil moisture deficit is low. The rate of growth is closely related to the transpiration rate which is itself a function of available energy; the quality of the hay is outside the present considerations.

(3) The closeness of the relationship provides still more evidence of a very strong character that the available figures for rainfall and potential transpiration are relatively accurate in England, even if the latter are only obtained by the approximate method.

(4) The establishment of reliable regression factors of yield on transpiration will enable good estimates to be made of the effect of grass irrigation during the first half of the growing season. This effect is of the order of ten per cent. per inch of water applied.

(5) The gradual general improvement in farming technique is clearly reflected in the post-war yield adjustment of about $\frac{1}{4}$ cwt/acre per year.

(6) Large errors occur in some regions in some years in only about one seventh of the calculations. These tend to disappear as the acreage considered increases.

(7) The largest source of error would seem to be lack of knowledge of the true period of growth, especially the date of harvest, and in the wetter regions, the weather during harvest.

(8) Success in this analysis encourages the application of this technique to the consideration of other similar crops.

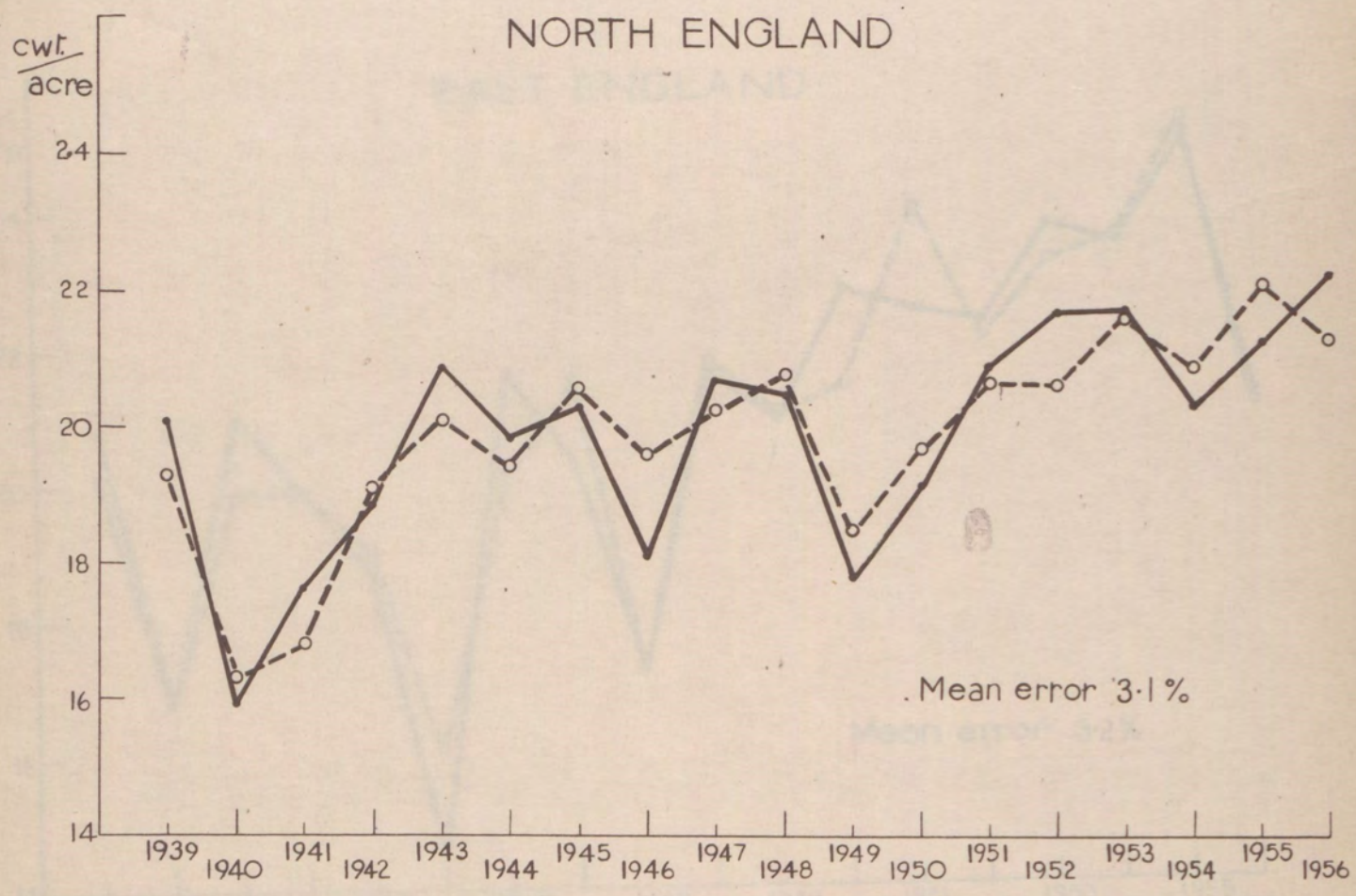
7. Acknowledgements

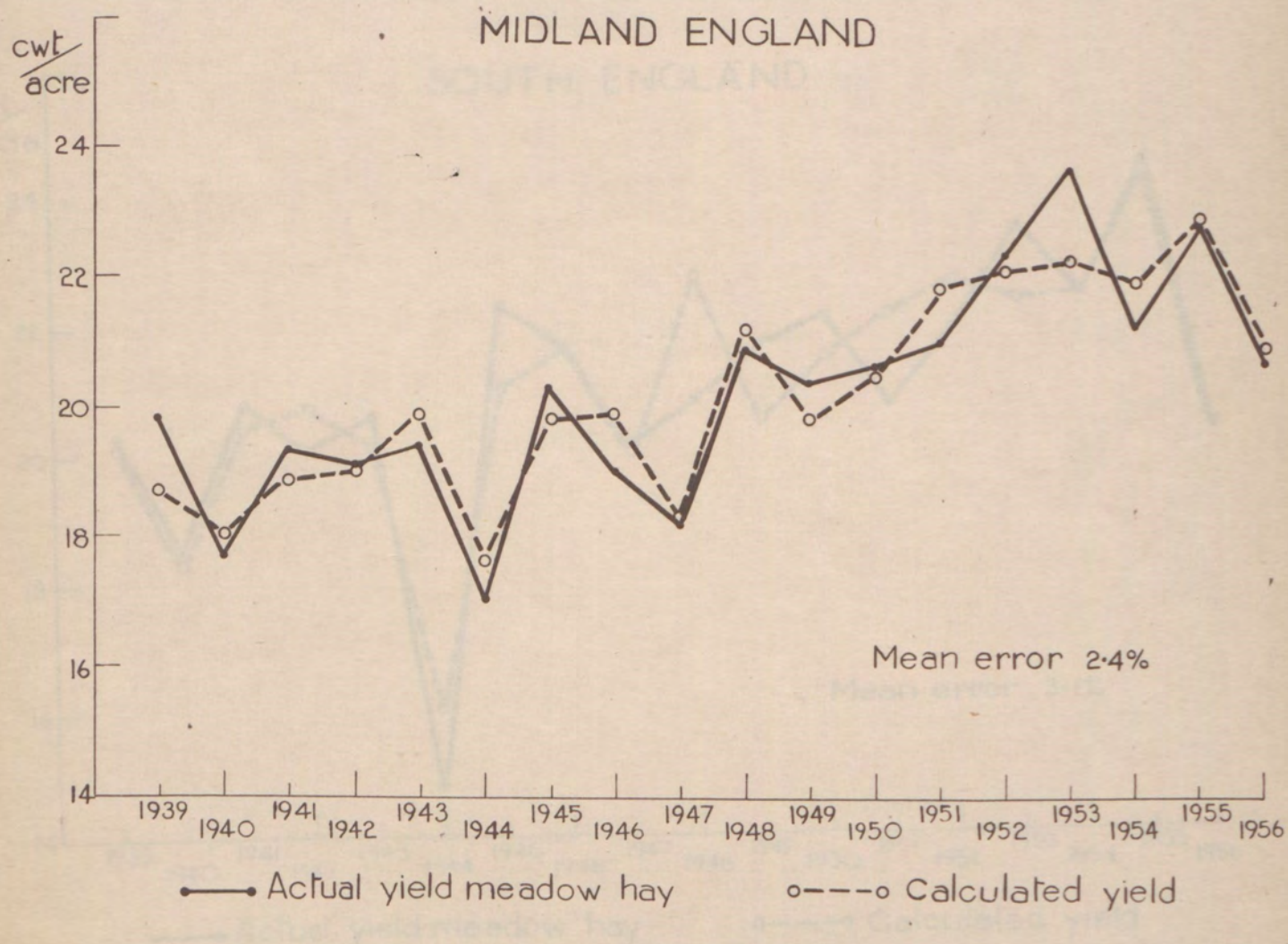
My thanks are due to Professor F. L. Milthorpe of Nottingham University, Dr. H. L. Penman of Rothamsted and Dr. R. S. Tayler of Reading University for their helpful criticism in the final drafting of this memorandum.

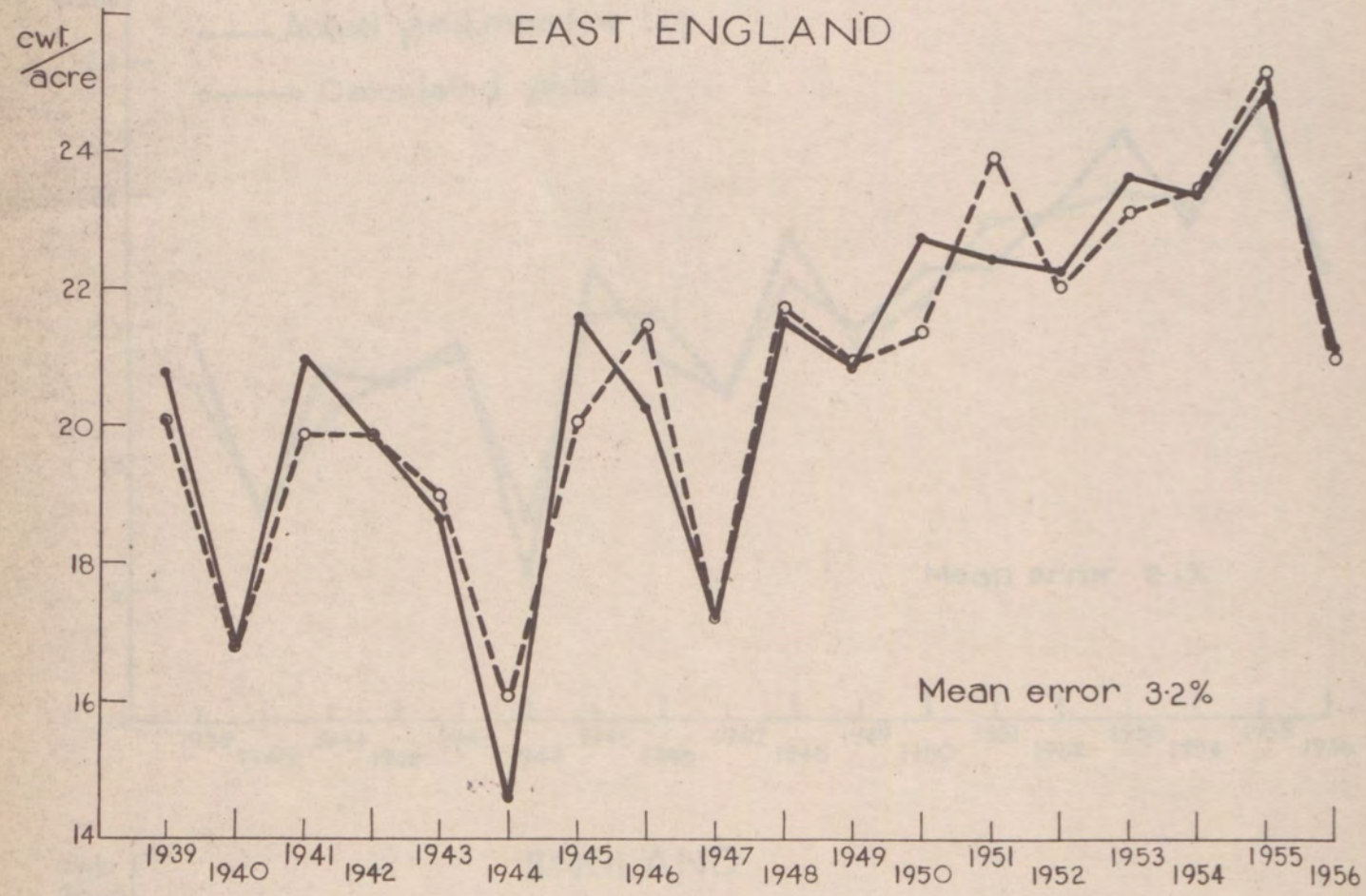
L. P. Smith

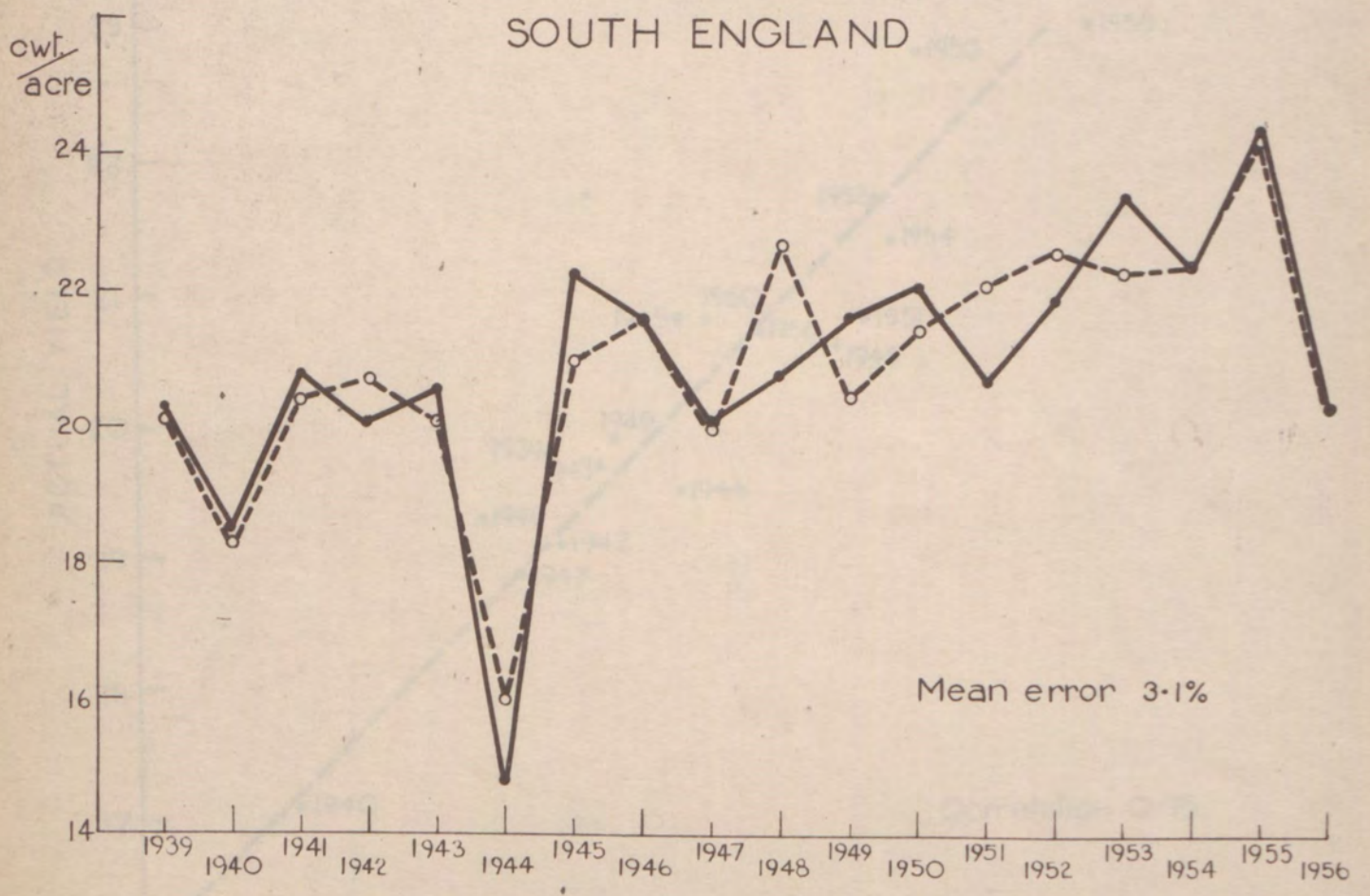
M.O.3a
January 1960
Agricultural Memorandum No. 27

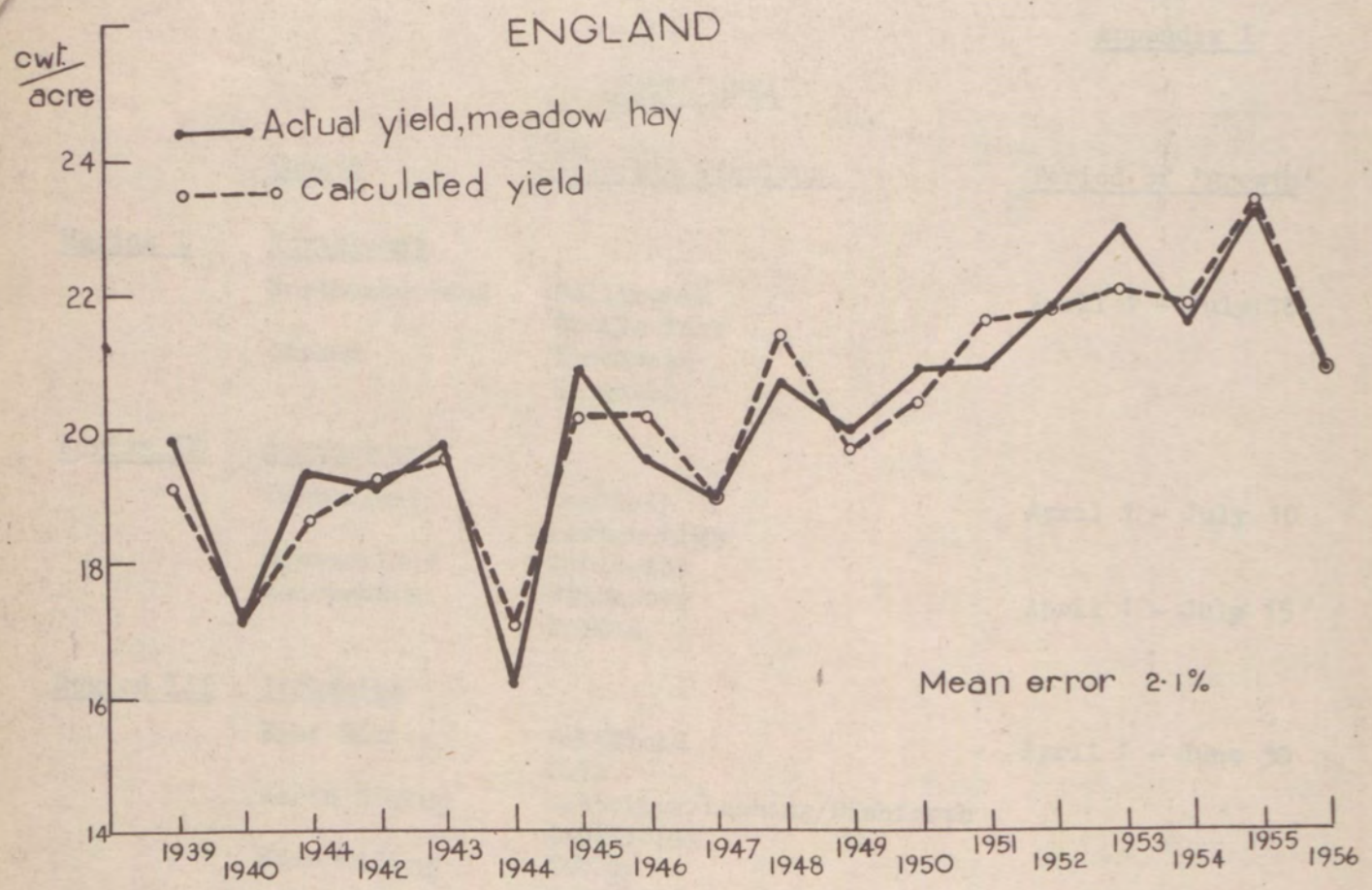
G.1321/CMM/2/60/100

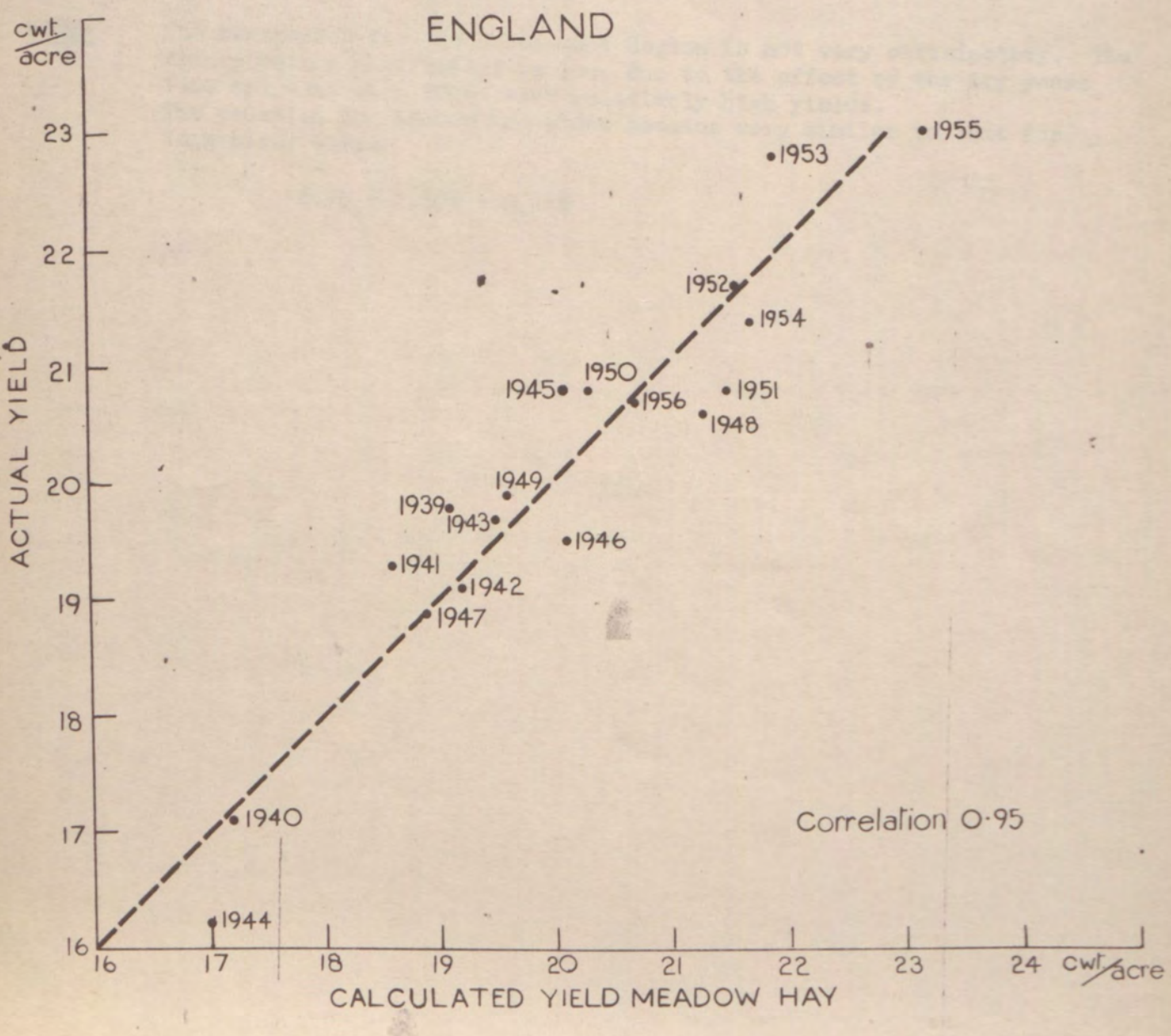

NORTH ENGLAND
cwt./acre
24
22
20
18
16
14
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
Mean error 3·1%


MIDLAND ENGLAND
cwt./acre
24
22
20
18
16
14
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
Mean error 2·4%
Actual yield meadow hay
Calculated yield


EAST ENGLAND
cwt./acre
24
22
20
18
16
14
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
Mean error 3·2%


SOUTH ENGLAND
cwt./acre
24
22
20
18
16
14
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
Mean error 3·1%
Actual yield meadow hay
Calculated yield


ENGLAND
cwt. / acre
Actual yield, meadow hay
Calculated yield
Mean error 2·1%
24
22
20
18
16
14
1939
1940
1944
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956


ENGLAND
cwt. / acre
ACTUAL YIELD
CALCULATED YIELD MEADOW HAY
Correlation 0·95
1955
1953
1952
1954
1945
1950
1956
1951
1948
1949
1939
1943
1946
1941
1942
1947
1940
1944
23
22
21
20
19
18
17
16
16
17
18
19
20
21
22
23
24
cwt. / acre

Appendix I

NORTH AREA

	County	Rainfall stations	Period of 'growth'
Region I	North-east		
	Northumberland	Bellingham	April 1 - July 10
		Cockle Park	
	Durham	Tynemouth	
		Houghall	
Region II	North-west		
	Cumberland	Carlisle	April 1 - July 10
		Newton Rigg	
	Westmorland	Ambleside	
	Lancashire	Blackpool	April 1 - July 15
		Bolton	
Region III	Yorkshire		
	East Riding	Driffield	April 1 - June 30
		Hull	
	North Riding	Catterick/Leeming/Dishforth	
		Ampleforth	
	West Riding	Ilkley	
		Wakefield	

NOTE: The regression for the North-west Region is not very satisfactory. The transpiration coefficient is low, due to the effect of the dry years 1940 and 1941 when there were relatively high yields.
The equation for Lancashire alone becomes very similar to that for Yorkshire, viz.:-

$$6.74 + 1.60T + 0.21N$$

NORTH ENGLAND

Formula 9.17 + 1.30T + 0.22N

Year	Yield	T	Calculated Yield	Error
1939	20.1	7.8	19.3	-0.8
1940	15.9	5.5	16.3	+0.4
1941	17.6	5.9	16.8	-0.8
1942	18.9	7.6	19.1	+0.2
1943	20.9	8.4	20.1	-0.8
1944	19.8	7.9	19.4	-0.4
1945	20.3	8.8	20.6	+0.3
1946	18.1	8.0	19.6	+1.5
1947	20.7	8.4	20.3	-0.4
1948	20.5	8.6	20.8	+0.3
1949	17.8	6.7	18.5	+0.7
1950	19.1	7.4	19.7	+0.6
1951	20.9	8.0	20.7	-0.2
1952	21.7	7.8	20.6	-1.1
1953	21.7	8.4	21.6	-0.1
1954	20.3	7.7	20.9	+0.6
1955	21.2	8.4	22.1	+0.9
1956	22.2	7.6	21.3	-0.9
Mean	19.9	7.7		0.61
			Mean percentage error	3.1%
			Correlation between actual and calculated yields	0.88

NORTH ENGLAND

Year	NORTHEAST			NORTHWEST			YORKSHIRE		
	Yield cwt/acre	T in.	Error	Yield cwt/acre	T in.	Error	Yield cwt/acre	T in.	Error
1939	21.2	7.6	-2.0	20.5	9.1	+0.1	19.2	6.9	-1.1
1940	16.1	5.7	+0.3	18.3	6.2	+0.7	13.9	4.9	+1.0
1941	18.0	5.9	-1.3	19.7	6.4	-0.6	15.7	5.4	0.0
1942	17.8	6.7	+0.1	19.4	8.6	+0.9	19.0	7.1	-0.6
1943	22.0	8.4	-1.7	22.0	9.6	-1.1	19.6	7.5	-0.5
1944	20.7	8.0	-0.9	20.8	8.8	-0.3	18.5	7.1	+0.1
1945	21.2	9.4	+0.6	20.9	9.7	+0.1	19.3	7.7	+0.1
1946	17.4	7.2	+1.2	19.0	8.8	+1.5	17.7	7.7	+1.7
1947	21.3	8.5	-0.4	21.6	9.0	-1.0	19.6	7.8	0.0
1948	20.1	8.5	+1.2	21.7	9.8	-0.5	19.7	7.7	+0.2
1949	15.5	5.3	+1.5	19.3	7.9	+0.6	17.7	6.3	+0.1
1950	19.6	7.2	+0.6	18.9	8.3	+1.7	19.1	6.7	-0.4
1951	21.7	8.4	+0.7	21.2	8.3	-0.5	20.4	7.6	0.0
1952	21.0	7.3	+0.1	23.1	9.5	-1.6	20.8	6.7	-1.7
1953	23.0	8.4	+0.2	21.1	9.5	+0.5	21.5	7.6	-0.7
1954	21.6	7.7	+0.8	20.7	8.9	+0.6	19.4	6.8	+0.3
1955	22.6	7.9	+0.5	22.1	9.9	-0.1	19.9	7.5	+1.2
1956	25.1	6.9	-3.0	22.6	8.5	-1.3	20.5	7.2	+0.3
Mean error			0.97			0.76			0.56
Mean percentage error			4.8%			3.7%			2.9%
Correlation between actual and calculated yields			0.87			0.76			0.90

Formulae

NORTHEAST Yield = 8.16 + 1.45T + 0.39N

NORTHWEST Yield = 15.45 + 0.57T + 0.10N

YORKSHIRE Yield = 6.94 + 1.62T + 0.22N

G.1321/CMM/2/60/100

MIDLAND AREA

	County	Rainfall stations	Period of 'growth'
Region IV	Northeast Midlands		
	Derbyshire	Belper	March 1 - June 30
	Lincolnshire	Cleethorpes	
		Doncaster/Finningley/ Lindholme	
		Cranwell	
		Spalding	
	Nottinghamshire	Mansfield	
		Sutton Bonington	
Region V	Central Midlands		
	Leicestershire	Leicester	March 1 - June 30
	Northamptonshire	Kettering	
		Towcester	
	Rutland	Ketton	
	Warwickshire	Birmingham	
		Leamington Spa	
Region VI	West Midlands		
	Cheshire	Delamere	March 1 - June 30
	Hereford	Ross	
	Shropshire	Shrewsbury	
	Staffordshire	Hanley/Mayfield	
		Walsall/Aldridge	
	Worcestershire	Worcester	

NOTE: (a) Doncaster etc. are not strictly in Lincolnshire, but the rainfall there is regarded as typical of the northwest of that county.

(b) The calculated yield for the Central Midlands in 1939 is conspicuously in error; the reason is unknown.

MIDLAND ENGLAND

Formula 7.28 + 1.45T + 0.27N

Year	Yield	T	Calculated Yield	Error
1939	19.8	7.9	18.7	-1.1
1940	17.7	7.4	18.0	+0.3
1941	19.3	8.0	18.9	-0.4
1942	19.1	8.1	19.0	-0.1
1943	19.4	8.7	19.9	+0.5
1944	17.0	7.1	17.6	+0.6
1945	20.3	8.6	19.8	-0.5
1946	19.0	8.7	19.9	+0.9
1947	18.2	7.4	18.3	+0.1
1948	20.9	9.2	21.2	+0.3
1949	20.4	8.1	19.8	-0.6
1950	20.6	8.4	20.5	-0.1
1951	21.0	9.1	21.8	+0.8
1952	22.3	9.1	22.1	-0.2
1953	23.6	9.0	22.2	-1.4
1954	21.2	8.6	21.9	+0.7
1955	22.8	9.1	22.9	+0.1
1956	20.7	7.5	20.9	+0.2
Mean	20.2	8.3		0.495

Mean percentage error	2.4%
Correlation between actual and calculated yields	0.94

MIDLAND ENGLAND

	NORTHEAST			CENTRAL			WEST		
Year	Yield cwt/acre	T in.	Error	Yield cwt/acre	T in.	Error	Yield cwt/acre	T in.	Error
1939	20.9	8.0	-1.2	20.0	7.6	-3.0	19.0	7.9	-0.1
1940	15.2	6.1	+0.9	16.8	7.2	-0.4	19.7	8.3	-0.2
1941	17.8	7.0	0.0	18.6	8.2	-0.9	20.5	8.4	-0.8
1942	20.8	8.1	-0.9	15.9	7.6	+1.1	19.6	8.4	+0.1
1943	19.0	8.2	+1.1	17.9	8.3	0.0	20.5	9.2	+0.4
1944	19.2	7.3	-0.8	14.6	7.1	+1.7	16.9	6.9	+0.5
1945	20.4	8.2	-0.3	18.6	8.1	-1.0	21.0	9.2	-0.1
1946	19.0	8.1	+0.9	18.7	9.0	+0.1	19.1	9.0	+1.5
1947	16.9	6.7	+0.4	16.1	6.9	+0.3	20.1	8.0	-0.7
1948	20.5	8.7	+0.6	19.2	9.3	+0.6	22.0	9.5	0.0
1949	20.4	7.6	-1.3	18.6	8.1	0.0	21.4	8.5	-0.5
1950	20.6	8.4	+0.1	19.8	9.2	+0.6	21.0	8.0	-0.5
1951	20.8	9.0	+0.9	19.4	9.3	+1.4	22.0	9.1	+0.5
1952	21.7	8.6	-0.5	20.4	9.2	+0.7	23.6	9.3	-0.5
1953	21.9	8.9	0.0	21.5	8.5	-1.0	25.8	9.4	-2.2
1954	20.5	8.2	+0.1	21.0	8.7	+0.1	21.8	8.8	+1.3
1955	22.4	8.9	-0.4	22.4	9.0	-0.6	23.3	9.3	+0.9
1956	19.7	7.7	+0.1	19.4	7.1	+0.3	21.8	7.6	+0.1
Mean error			**0.58**			0.77			0.61
Mean percentage error			2.9%			4.1%			2.9%
Correlation between actual and calculated yields			0.91			0.88			0.91

Formulae

NORTHEAST MIDLANDS Yield = 4.57 + 1.89T + 0.07N

CENTRAL MIDLANDS Yield = 7.15 + 1.29T + 0.34N

WEST MIDLANDS Yield = 6.81 + 1.53T + 0.35N

Appendix III

EAST AREA

	County	Rainfall stations	Period of 'growth'
Region VII	Southeast Midlands		
	Bedfordshire	Sandy	March 1 - June 15
	Cambridgeshire (plus the Isle of Ely)	March Cambridge	
	Hertfordshire	Rothamsted	
	Huntingdonshire (plus the Soke of Peterborough)	St Ives	
Region VIII	East Anglia		
	Essex	Saffron Walden Hatfield Peverel	March 1 - June 15
	Norfolk	King's Lynn Swaffham Sprowston	
	Suffolk	Lowestoft Felixstowe Mildenhall	
Region IX	Southeast		
	Kent	Wilmington East Malling Margate Wye	March 1 - June 15
	Middlesex	Wealdstone	
	Surrey	Kew Croydon	
	Sussex	Hawkhurst Chichester	

NOTE: The very low yield in 1944 for the Southeast Midlands is not fully accounted for.

EAST ENGLAND

Formula 2.38 + 2.22T + 0.37N

Year	Yield	T	Calculated Yield	Error
1939	18.8	7.1	18.1	-0.7
1940	14.9	5.6	14.8	-0.1
1941	19.0	7.0	17.9	-1.1
1942	17.9	7.0	17.9	0.0
1943	16.7	6.6	17.0	+0.3
1944	12.6	5.3	14.1	+1.5
1945	19.6	7.1	18.1	-1.5
1946	18.3	7.7	19.5	+1.2
1947	15.2	5.6	15.2	0.0
1948	19.6	7.5	19.8	+0.2
1949	18.9	7.0	19.0	+0.1
1950	20.8	7.0	19.4	-1.4
1951	20.5	8.0	22.0	+1.5
1952	20.3	7.0	20.1	-0.2
1953	21.7	7.3	21.2	-0.5
1954	21.4	7.3	21.5	+0.1
1955	22.9	7.9	23.2	+0.3
1956	19.2	5.8	19.0	-0.2
Mean	18.8	6.9		0.605
Mean percentage error				3.2%
Correlation between actual and calculated yields				0.94

EAST ENGLAND

Year	SOUTHEAST MIDLANDS			EAST ANGLIA			SOUTHEAST		
	Yield cwt/acre	T in.	Error	Yield cwt/acre	T in.	Error	Yield cwt/acre	T in.	Error
1939	19.7	7.4	-1.3	20.2	6.8	-1.7	16.8	7.1	+0.6
1940	15.5	6.1	0.0	15.1	5.5	+0.1	14.3	5.5	+0.1
1941	18.2	7.1	-0.4	19.7	6.5	-2.0	18.7	7.4	-0.7
1942	17.9	6.9	-0.6	18.2	6.6	-0.2	17.6	7.5	+0.6
1943	17.6	7.0	+0.1	16.0	6.0	+0.5	17.0	7.1	+0.4
1944	10.9	5.6	+3.5	13.8	5.3	+0.9	12.2	5.0	+1.3
1945	18.5	7.1	-0.7	20.5	7.2	-1.0	19.3	7.0	-2.1
1946	17.9	7.8	+1.4	17.9	7.3	+1.8	19.0	8.0	+0.1
1947	16.4	5.5	-1.9	12.9	4.9	+1.1	17.0	6.4	-0.5
1948	21.0	8.5	+0.7	19.0	7.2	+1.0	19.4	7.2	-0.9
1949	20.8	7.2	-1.7	19.4	7.0	+0.4	17.1	7.0	+1.4
1950	20.6	7.6	-0.2	21.8	6.9	-2.0	20.0	6.8	-1.4
1951	21.4	8.2	+0.7	21.0	7.9	+1.6	19.4	8.0	+1.9
1952	20.0	7.4	+0.7	20.8	6.7	-0.9	19.9	7.1	+0.1
1953	21.4	7.6	+0.1	22.6	7.3	-0.9	21.1	7.1	-0.7
1954	22.2	7.5	-0.6	21.7	7.4	+0.5	20.7	7.2	+0.4
1955	23.2	8.1	+0.2	22.1	7.5	+0.6	23.5	8.2	-0.1
1956	18.8	6.0	+0.2	18.6	5.6	-0.3	19.8	5.9	-0.3
Mean error			0.83			0.97			0.76
Mean percentage error			4.4%			5.1%			4.1%
Correlation between actual and calculated yields			0.91			0.91			0.92

Formulae

SOUTHEAST MIDLANDS	Yield = 1.72 + 2.26T + 0.37N
EAST ANGLIA	Yield = 1.40 + 2.51T + 0.28N
SOUTHEAST ENGLAND	Yield = 4.01 + 1.89T + 0.43N

Appendix IV

SOUTH AREA

	County	Rainfall stations	Period of 'growth'
Region X	South Midlands		
	Berkshire	Reading Wantage	March 1 - June 30
	Buckinghamshire	Newport Pagnell Great Missenden	
	Gloucester	Cheltenham Bristol	
	Oxford	Chipping Norton Oxford	
Region XI	South Central		
	Dorset Hampshire	Blandford Leckford South Farnborough Portsmouth Bournemouth	March 1 - June 30
	Isle of Wight	Newport	
	Wiltshire	Marlborough Boscombe Down	
Region XII	Southwest		
	Cornwall	Newquay Lizard St. Austell	March 1 - June 15
	Devon	Plymouth Hartland Point Exeter	
	Somerset	Cannington Martock	

NOTE: The South Midland area is not very homogeneous and the results reflect this disadvantage.

SOUTH ENGLAND

Formula $7.65 + 1.57T + 0.25N$

Year	Yield	T	Calculated Yield	Error
1939	20.3	7.9	20.1	-0.2
1940	18.5	6.8	18.3	-0.2
1941	20.8	8.1	20.4	-0.4
1942	20.1	8.3	20.7	+0.6
1943	20.6	7.9	20.1	-0.5
1944	14.8	5.3	16.0	+1.2
1945	22.3	8.5	21.0	-1.3
1946	21.6	8.9	21.6	0.0
1947	20.1	7.7	20.0	-0.1
1948	20.8	9.3	22.7	+1.9
1949	21.6	7.7	20.5	-1.1
1950	22.1	8.1	21.4	-0.7
1951	20.7	8.4	22.1	+1.4
1952	21.9	8.6	22.6	+0.7
1953	23.4	8.2	22.3	-1.1
1954	22.4	8.1	22.4	0.0
1955	24.4	9.1	24.2	-0.2
1956	20.3	6.5	20.3	0.0
Mean	20.9	8.0		0.645
Mean percentage error				3.1%
Correlation between actual and calculated yields				0.90

SOUTH ENGLAND

	SOUTH MIDLANDS			SOUTH CENTRAL			SOUTHWEST		
Year	Yield cwt/acre	T in.	Error	Yield cwt/acre	T in.	Error	Yield cwt/acre	T in.	Error
1939	21.0	8.4	-1.1	20.4	8.4	-0.1	19.6	7.2	+0.5
1940	17.4	7.1	+0.3	17.0	6.1	-0.2	20.7	7.0	-0.8
1941	20.4	8.0	-1.2	20.3	8.8	+0.6	21.4	7.7	-0.5
1942	19.2	8.0	0.0	19.8	8.7	+0.9	20.9	8.2	+0.7
1943	19.1	7.9	0.0	20.8	7.8	-1.4	21.6	7.9	-0.4
1944	12.6	5.2	+1.9	13.7	5.4	+2.1	17.2	5.3	+0.1
1945	22.5	8.7	-2.1	22.9	9.0	-1.7	21.8	8.0	-0.5
1946	20.4	9.0	+0.5	22.6	9.8	-0.2	21.7	8.1	-0.2
1947	18.7	7.2	-0.6	20.3	8.0	-0.3	21.0	7.8	+0.2
1948	20.6	9.8	+2.1	21.0	10.1	+2.5	20.9	8.3	+1.2
1949	20.2	8.1	-0.1	22.0	7.4	-2.3	22.2	7.7	-0.7
1950	23.8	9.0	-2.0	21.9	8.2	-0.6	21.0	7.4	+0.2
1951	19.9	8.8	+1.8	21.2	8.7	+1.1	20.8	7.9	+1.3
1952	20.6	9.1	+1.9	22.3	8.9	+0.6	22.4	8.1	+0.2
1953	22.1	8.7	-0.1	23.9	8.7	-0.9	23.9	7.6	-1.8
1954	22.1	8.7	+0.2	23.2	8.7	+0.1	22.0	7.3	-0.2
1955	24.0	9.4	-0.3	26.0	10.0	-0.4	23.6	8.2	-0.3
1956	20.9	6.8	-1.4	20.6	6.8	+0.5	19.8	6.2	+0.8
Mean error			0.98			0.92			0.59
Mean percentage error			4.9%			4.3%			2.8%
Correlation between actual and calculated yields			0.86			0.90			0.86

Formulae

SOUTH MIDLANDS Yield = 5.80 + 1.68T + 0.23N

SOUTH CENTRAL Yield = 7.68 + 1.50T + 0.32N

SOUTHWEST Yield = 9.56 + 1.47T + 0.19N

G.1321/CMM/2/60/100